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<b>(54) Title:</b> WATER-BASED AMALGAM ADHESIVE  <b>(57) Abstract</b>  Dental adhesive containing water, acid-reactive filler, water-miscible acidic polymer, an ethylenically-unsaturated moiety, water-soluble reducing agent, water-soluble oxidizing agent and, optionally, photoinitiator. The adhesive has two curing modes, namely an acid-filler ionic reaction and a redox-initiated crosslinking reaction, and optionally, a photoinitiated crosslinking curing mode. The adhesive can be applied in one coat or two coats and is particularly well suited for use under amalgam.		

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**WATER-BASED AMALGAM ADHESIVE**

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**Technical Field**

This invention relates to dental adhesives, and especially amalgam adhesives.

**Background Art**

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Dental amalgams and restorative composites are used extensively for intracoronal and extracoronal restorations. Amalgam, however, does not adhere to tooth structure and the dentist must prepare the tooth cavity with dovetails and various cutout grooves that mechanically lock the amalgam into the cavity. Such preparation, however, results in excavation of more tooth structure than would otherwise be necessary if there was good adhesion between the tooth structure and the amalgam. Moreover, leakage at the interface of the amalgam and cavity wall (known as "microleakage") tends to occur. This microleakage allows penetration of bacteria, soluble salts, and saliva into any space between the amalgam and tooth structure. This can lead to inflammation, pulp irritation, demineralization of the tooth, corrosion of the amalgam, and other attendant complications. An adhesive seal between amalgam and tooth structure could minimize and/or prevent microleakage and allow for a stronger restoration due to excavation of less tooth material.

30

Products claiming to make amalgam adhesive to tooth structure are available. One such product is sold in a kit under the trademark AMALGAMBOND™ (Parkell Co.). This product is a liquid adhesive to be coated directly onto tooth structure. The active ingredients in the adhesive include 4-META (4-methacryloxyethyl trimellitic anhydride) and TBB (tri-n butyl borane). Other products which similarly involve coating a

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specific curable resin directly onto tooth structure to make amalgam adhere are available under the trademarks PANAVIA™ Dental Adhesive (Kuraray Company) and SUPERBOND™ Adhesive (Sun Medical Co., Ltd., Kyoto, Japan). These latter products also are difficult to employ, since there are a number of required preparatory steps for their application and curing.

Articles that describe bonding of amalgam to tooth structure by precoating the tooth with ethylenically unsaturated adhesive resin include M. Staninec and M. Holt, Journal of Prosthetic Dentistry (1988), Vol. 59, pp. 397-402, A. Lacey and M. Staninec, Quintessence International (1989), Vol. 20, pp. 521-524, Y. Aboush and C. Jenkins, Br. Dent. J. (1989), Vol. 166, pp. 255-257, Y. Aboush and R. Elderton, Br. Dent. J. (1991), Vol. 170, pp. 219-222, and Y. Aboush and R. Elderton, Dent. Mater. (1991), Vol. 7, pp. 130-132. The last article involves adhesion to previously-hardened amalgam, whereas the other articles involve adhesion to fresh amalgam. Also, A. Ben-amar, J. Am.

Dent. Assoc. (1989), Vol. 119, pp. 725-728, describes a reduction in microleakage at the margins of amalgam restorations when "SCOTCHBOND" Dual Cure Dental Adhesive resin (3M) is applied to cavity margins prior to application of amalgam, and M. Mitrosky, Jr., Quintessence International (1981), Vol. 9, pp. 871-874, describes the use of ethyl cyanoacrylate as a bonding agent beneath amalgam and composite restoratives. H. J. Staehle et al., Dtsch. Zahnartzt (1988), Vol. 43, pp. 952-957, describes the use of various dental adhesives and varnishes to adhere amalgam to dentin.

U.S. Pat. No. 3,513,123 (Saffir) describes a curable epoxy composition that can be added to amalgam in order to make the amalgam adhere to tooth structure. The curable epoxy composition contains a glycidyl ether epoxy resin and a polyamine hardening agent.

U.S. Pat. No. 4,064,629 (Stoner) describes a method for applying amalgam restorations. The method involves precoating the surfaces of a cavity within a cari us tooth with a layer of an "adhesive-metal" lining composition. The metal of the lining composition is amalgamated by diffusion of the mercury from the subsequently applied conventional dental amalgam filling. The "adhesive-metal" lining composition is said to improve corrosion resistance of the dental amalgam filling and also to promote bonding between the amalgam restoration and the cavity surfaces.

U.S. Pat. No. 4,001,483 (Lee, Jr. et al.) describes dental compositions for sealing margins between tooth structures and amalgam restorations therein, the compositions containing (a) an alkylene glycol dimethacrylate and/or its oligomer, (b) a polymerization initiator, (c) a polymerization accelerator and (d) a secondary monomer additive.

U.S. Pat. No. 3,574,943 (Stark) describes a method of restoring a carious tooth whereby the cavity is excavated, lined with a layer of a polysiloxane pressure sensitive adhesive polymer dissolved in a fluorocarbon, and filled with amalgam. The polysiloxane layer is said to act as a barrier to leakage.

Japanese Kokai 63-175085 describes an adhesive composition comprising an acid functional monomer, polymer, or copolymer, a vinyl monomer in which the acid functional component is soluble, an organic peroxide, and an aromatic amine or sulfinat salt. The composition is said to bond living tooth tissue to composites and amalgams.

Japanese Kokai 63-250310 describes dental adhesive compositions containing (a) cellulose ether, (b) a vinyl monom r, (c) an organic peroxide, and (d) an aromatic amine or a sulfinat . The composition is

said to be applicable to a wide variety of restorative materials, including composite resins, amalgam, alumina, gold, alloys, polymethyl methacrylate, polycarbonate, and the like.

5                   French Patent 2,561,521 describes an intermediate adhesive composition for sealing dental cavities and chemically securing amalgams, comprising a metal powder dispersed in an adhesive varnish. The composition contains metal powder, cellulosic varnish,  
10 ethyl acetate, amyl propionate, fluoride, and oil of pimento leaf.

#### Other Art

It is also worth noting that a number of  
15 water-based cements are used in dentistry. These water-based cements may contain some of the same ingredients as water-based adhesives, but are distinguished from adhesives by having much higher viscosity and by being intended for use in load-bearing applications. Examples include metal oxide cements  
such as those described in U.S. Pat. No. 3,633,000 and fluoroaluminosilicate glass cements (also known as "glass ionomer cements") such as those described in Example 6 of the '605 patent and in U.S. Pat. Nos.  
25 3,814,717, 4,043,327, 4,143,018, 4,209,434 and 4,872,936; European Pat. Application Nos. 0 323 120 and 0 329 268; and Australian Published Pat. Specification No. 46717/89. These water-based cements have also  
found utility in medical applications such as the  
30 fabrication of orthopedic bandages, as described in U.S. Pat. Nos. 4,043,327 and 4,243,567.

A light-curable and apparently anhydrous cement is shown in European Pat. Application No. 0 391 619. It contains a number of ingredients, including  
35 benzoyl peroxide.

Summary of the Invention

The present invention provides a water-based dental adhesive kit that can be used to adhere fresh (unhardened) amalgam to dentin. The kit contains at least one adhesive having two "dark" curing modes, i.e., curing modes that will proceed in the absence of light. The first curing mode employs an ionic reaction between acidic and inorganic filler components of the adhesive. The second curing mode employs a redox-initiated free radical crosslinking reaction involving an ethylenically-unsaturated component of the adhesive. The adhesive optionally cures through a third curing mode, via photoinitiated free radical crosslinking of the ethylenically-unsaturated component.

The adhesive is water-based, and thus can be used under moist conditions such as are typically present in the mouth. The adhesive is applied to tooth structure in one or more first coats followed by one or more subsequent or second coats. Each coat employs both the ionic curing mode and the redox-initiated curing mode. The initial coat or coats may optionally utilize a photoinitiated cure mode. If desired, different adhesives can be employed for the first and subsequent coats. However, for reasons of packaging economy and simplicity of use, the kit preferably contains only a single adhesive composition.

The adhesive for the first coat or coats (the "First Adhesive") comprises a water-containing, ionically-hardenable, ethylenically-unsaturated dental adhesive, comprising

- (a) finely-divided acid-reactive filler,
- (b) water-miscible acidic polymer, and
- (c) either a photoinitiator or a water-soluble reducing agent and a water-soluble oxidizing agent; or both the photoinitiator and the reducing agent/oxidizing agent pair.



The adhesive for the subsequent coat or coats (the "Second Adhesive") comprises the above ingredients (a), (b), and optional photoinitiator as ingredient (c), (c), together with

- 5 (d) water-soluble reducing agent, and  
(e) water-soluble oxidizing agent.

Preferably, the reducing agent and the oxidizing agent are capable of initiating gelation of a 10:10:1 (weight basis) water:acrylamide:methylene bis-acrylamide  
10 mixture.

In a further aspect, the invention provides preferred adhesives in which the reducing agent or the oxidizing agent are contained in microcapsules. The microcapsules improve shelf life and facilitate  
15 packaging.

#### Detailed Description

Generally, both the First Adhesive and the Second Adhesive are formulated in two parts, although  
[REDACTED] can be made  
up if desired. In a two part formulation, the first part typically is a powder portion containing the acid-reactive filler. The second part typically is a liquid portion containing the acidic polymer and water.

25 For the Second Adhesive, the liquid portion typically also contains one (but usually not both) of the water-soluble reducing agent and water-soluble oxidizing agent. If the reducing agent is present in the liquid portion of the Second Adhesive, then the  
30 oxidizing agent is typically present in the powder portion, and vice-versa. The reducing agent and oxidizing agent can be combined in the powder portion or in the liquid portion through the use of a microencapsulation technique described in more detail  
35 below.

The invention is not limited to powder:liquid formulations. For example, one part anhydrous



formulations containing filler, polymer, reducing agent and oxidizing agent can be prepared. These can be sold in dry form and prepared for use by adding water.

Also, two part paste:paste formulations can be prepared by adding to the acid-reactive filler a suitable polymerizable liquid that does not react with that filler (e.g., 2-hydroxyethyl methacrylate, or "HEMA"), yielding a first paste. The acidic polymer described above is combined with a suitable filler that does not react with the acidic polymer (e.g., ground quartz), yielding a second paste. The two pastes are prepared for use by stirring them together. The combined pastes preferably have a sufficiently low filler loading and sufficiently low viscosity so that their mixture will be useful as a dental adhesive. Other useful configurations will be familiar to those skilled in the art. However, for simplicity, the remainder of this patent specification will refer to powder:liquid formulations unless specifically noted otherwise.

Both the First Adhesive and the Second Adhesive contain water. The water can be present in the product as sold, or added by the dentist just prior to use. The water can be distilled, deionized or plain tap water. Generally, deionized water is preferred. The amount of water should be sufficient to provide adequate handling and mixing properties and to permit the transport of ions in the filler-acid reaction. Preferably for both the First Adhesive and the Second Adhesive, water represents at least about 1%, more preferably about 3% to about 60%, and most preferably about 5% to about 40% of the total weight of ingredients used to form the adhesive.

Both the First Adhesive and the Second Adhesive are ionically hardenable. By this is meant that they contain ingredients that, when combined, can react via an ionic reaction to produce a hardened mass. The

ionic reaction occurs between acid groups on the polymer and acid-reactive groups on the filler.

Both the First Adhesive and the Second Adhesive are ethylenically-unsaturated. In other words, they contain at least one ethylenically-unsaturated moiety. The ethylenically-unsaturated moiety can be present as a separate ingredient (for example, as an acrylate- or methacrylate-functional monomer) or it can, if desired, be present as a group on another ingredient such as the acidic polymer. A wide variety of ethylenically-unsaturated moieties can be used. A useful list of suitable materials is shown at page 9, line 13 through page 13, last line of Australian Published Pat. Specification No. 46717/89. Of the many materials mentioned, water-miscible or water-soluble acrylates and methacrylates such as 2-hydroxyethyl methacrylate, hydroxymethyl methacrylate, 2-hydroxypropyl methacrylate, tetrahydrofurfuryl methacrylate, glycerol mono- or di-methacrylate, trimethylol propane

polyethylene glycol dimethacrylate, urethane methacrylates, acrylamide, methacrylamide, methylene bis-acrylamide or methacrylamide, and diacetone acrylamide and methacrylamide are preferred. Mixtures of ethylenically-unsaturated moieties can be used if desired. Preferably, the ethylenically-unsaturated moieties are present as groups on the acidic polymer, as described in more detail below.

Both the First Adhesive and the Second Adhesive contain an acid-reactive filler. The filler should be sufficiently finely-divided so that it can be conveniently mixed with the other adhesive ingredients and used in the mouth. Preferred average particle diameters for the filler in both the First Adhesive and the Second Adhesive are about 0.2 to about 15 micrometers, more preferably about 1 to 10 micrometers,

as measured using, for example, a sedimentation analyzer.

- Suitable acid-reactive fillers include metal oxides, metal salts and glasses. Preferred metal oxides include barium oxide, calcium oxide, magnesium oxide and zinc oxide. Preferred metal salts include salts of multivalent cations, for example aluminum acetate, aluminum chloride, calcium chloride, magnesium chloride, zinc chloride, aluminum nitrate, barium nitrate, calcium nitrate, magnesium nitrate, strontium nitrate and calcium fluoroborate. Preferred glasses include borate glasses, phosphate glasses and fluoroaluminosilicate glasses. Suitable fillers are also available from a variety of commercial sources familiar to those skilled in the art. For example, "GC Fuji LC" adhesive and "Kerr XR" ionomer cements, such as commercially available glass ionomer cements, such as "Mixture of fillers can be used if desired."
- If desired, the filler can be subjected to a surface treatment. Suitable surface treatments include acid washing, treatment with phosphates, treatment with chelating agents such as tartaric acid, treatment with a silane as described in Australian Published Pat. No. 46717/89, and treatment with a silanol solution.
- The amount of filler should be sufficient to provide an adhesive having desirable mixing and handling properties before hardening, and good adhesive performance after hardening. For both the First Adhesive and the Second Adhesive, the filler preferably represents less than about 90%, more preferably about 25% to about 85%, and most preferably about 30% to about 75% by weight of the total weight (including water) of the unhardened adhesive components.
- The acidic polymer need not be entirely water-soluble, but it should be at least sufficiently water-

miscible so that it does not undergo substantial separation when combined with the liquid ingredients of the adhesives. Suitable acidic polymers include those listed at column 2, line 62 through column 3, line 6 of U.S. Patent No. 4,209,434. Preferred acidic polymers include homopolymers and copolymers of alkenoic acids such as acrylic acid, itaconic acid and maleic acid. Suitable polymers are also available from a wide variety of commercial sources, and many are found in currently-available glass ionomer cements. As will be appreciated by those skilled in the art, the polymer should have a molecular weight sufficient to provide good storage, handling and mixing properties. For both the First Adhesive and the Second Adhesive, a preferred molecular weight is about 2000 to about 100,000 weight average molecular weight ( $\bar{M}_w$ ), evaluated against a polystyrene standard using gel permeation chromatography. The acidic polymer contains one or more ethylenically-unsaturated groups. Suitable

~~polymers are described~~

in U.S. Pat. No. 4,872,936 and in European Pat. Application No. 0 323 120. Preferably, the numbers of acid groups and ethylenically-unsaturated groups are adjusted to provide an appropriate balance of properties in each adhesive, both during the setting reaction and after the adhesive has hardened. For both the First Adhesive and the Second Adhesive, acidic polymers in which about 10 to about 30% of the acidic groups have been replaced with ethylenically-unsaturated groups are preferred.

The amount of acidic polymer in each adhesive should also be sufficient to provide a desired balance of physical properties. For both the First Adhesive and the Second Adhesive, a preferred acidic polymer amount is at least about 5%, more preferably about 10 to about 50%, and most preferably about 10 to about 30%

-11-

of the total weight (including water) of the unhardened adhesive components.

The optional photoinitiator should be capable of promoting free radical crosslinking of the ethylenically-unsaturated component on exposure to light of a suitable wavelength and intensity. It also preferably is sufficiently shelf-stable and free of undesirable coloration to permit its storage and use under typical dental conditions. Visible light photoinitiators are preferred. The photoinitiator preferably is water-soluble or water-miscible. Photoinitiators bearing polar groups usually have a sufficient degree of water-solubility or water-miscibility. The photoinitiator frequently can be used alone but typically it is used in combination with a suitable donor compound or a suitable accelerator (for example, amines, peroxides, phosphorus compounds, ketones and alpha-diketone compounds).

Preferred visible light-induced initiators include camphorquinone (which typically is combined with a suitable hydrogen donor such as an amine), diaryliodonium salt or metal complex salts, chromophore-substituted halomethyl-s-triazines and halomethyl oxadiazoles. Particularly preferred visible light-induced photoinitiators include combinations of an alpha-diketone, e.g., camphorquinone, and a diaryliodonium salt, e.g., diphenyliodonium chloride, bromide, iodide or hexafluorophosphate, with or without additional hydrogen donors (such as sodium benzene sulfinate, amines and amine alcohols).

Preferred ultraviolet light-induced polymerization initiators include ketones such as benzyl and benzoin, and acyloins and acyloin ethers. Preferred commercially available ultraviolet light-induced polymerization initiators include 2,2-dimethoxy-2-phenylacetophenone ("IRGACURE 651") and

benzoin methyl ether (2-methoxy-2-phenylacetophenone), both from Ciba-Geigy Corp.

The photoinitiator should be present in an amount sufficient to provide the desired rate of photopolymerization. This amount will be dependent in part on the light source, the thickness of the adhesive layer to be exposed to radiant energy, and the extinction coefficient of the photoinitiator. Typically, the photoinitiator components for both the First Adhesive and the Second Adhesive will be present at a total weight of about 0.01 to about 5%, more preferably from about 0.1 to about 5%, based on the total weight (including water) of the unhardened adhesive components. The photoinitiator can be included in either the powder or liquid parts of each adhesive.

The water-soluble reducing agent and water-soluble oxidizing agent are most conveniently discussed together. They should react with or otherwise

~~to produce free radicals~~  
capable of initiating polymerization of the ethylenically-unsaturated moiety. The reducing agent and oxidizing agent preferably are sufficiently shelf-stable and free of undesirable colorization to permit their storage and use under typical dental conditions. They should be sufficiently water-soluble to permit ready dissolution in (and discourage separation from) the other components of the Second Adhesive.

Preferably, the reducing agent and oxidizing agent should be sufficiently soluble that at least 200 parts per million may be readily dissolved in water, and no undissolved material will be observed after the solution has rested for one week. The reducing agent and oxidizing agent should also be sufficiently soluble and present in an amount sufficient to permit an adequate free radical reaction rate. This can be evaluated by combining all of the ingredients of the



-13-

Second Adhesive except for the filler under safelight conditions, and observing whether or not a hardened mass is obtained.

- The reducing agent and oxidizing agent preferably are sufficiently water-soluble and have sufficient gelation and oxidation potentials to initiate gelation of an aqueous crosslinkable acrylamide solution. This can be evaluated by adding 2 weight % each of the reducing agent and the oxidizing agent to an aqueous acrylamide:methylene bis-acrylamide solution (described below in Table Ia) and observing whether or not gelation occurs within 30 minutes. Preferably gelation should be observed within 7 minutes at 37°C and 90% relative humidity. Useful reducing agent/oxidizing agent pairs are shown in "Redox Polymerization", G. S. Misra and U. D. N. Bajpai, Prog. Polym. Sci., 8, 61-131 (1982).
- Preferred reducing agents include ascorbic acid, cobalt (II) chloride, ferrous chloride, ferrous sulfate, hydrazine, hydroxylamine (depending upon the choice of oxidizing agent) oxalic acid, thiourea, and salts of a dithionite or sulfite anion. Preferred oxidizing agents include cobalt (III) chloride, tert-butyl hydroperoxide, ferric chloride, hydroxylamine (depending upon the choice of reducing agent), perboric acid and its salts, and salts of a permanganate or persulfate anion. Hydrogen peroxide can also be used, although it may interfere with the optional photoinitiator if the latter is present.
- The amount of reducing agent and oxidizing agent should be sufficient to provide the desired degree of polymerization of the ethylenically-unsaturated component. The preferred amount for each of the reducing agent and oxidizing agent is about 0.01 to about 10%, more preferably about 0.02 to about 5%, based on the total weight (including water) of the unhardened Second Adhesive components.



As mentioned above, the reducing agent or the oxidizing agent can be microencapsulated. This will generally enhance shelf stability and permit packaging both the reducing agent and oxidizing agent together.

- 5 For example, through appropriate selection of the encapsulant, both the oxidizing agent and reducing agent can be combined with the filler and kept in a storage-stable state. Likewise, through appropriate selection of a water-insoluble encapsulant, the
- 10 reducing agent and oxidizing agent can be combined with water and the acidic polymer and maintained in a storage-stable state.

- Either water-soluble or water-insoluble encapsulants can be employed. However, water-insoluble
- 15 encapsulants are preferred, as they generally provide better long term storage stability under moist or humid conditions. Although the use of a water-insoluble encapsulant may initially seem inappropriate in a water-based adhesive, it has been found that vigorous

~~the use of a water-insoluble encapsulant will be sufficient to break~~  
apart the capsule walls and permit adequate release of the encapsulated reducing agent or oxidizing agent and subsequent hardening or cure of the Second Adhesive.

- Preferably the encapsulant is a medically
- 25 acceptable polymer and a good film former. Also, the glass transition temperature ( $T_g$ ) of the encapsulant preferably is above room temperature.

- A wide variety of encapsulants can be used, with cellulosic materials such as cellulose acetate,
- 30 cellulose acetate butyrate, ethyl cellulose, hydroxymethyl cellulose and hydroxyethyl cellulose being preferred. Other encapsulants include polystyrene, copolymers of polystyrene with other vinylic monomers, polymethylmethacrylate, copolymers of
- 35 methylmethacrylate with other ethylenically-unsaturated monomers, and other materials that will be familiar to those skilled in the art of encapsulation.

Th capsules themselves need not be perfectly spherical nor uniformly shaped. It is merely sufficient that they entrain or entrap the encapsulated reducing agent or oxidizing agent in a manner

5 sufficient to permit storage of the encapsulated material in the Second Adhesive without leading to undesirable premature polymerization.

To encapsulate the reducing agent or oxidizing agent in a water-insoluble encapsulant, it is preferred

10 to dissolve the encapsulant in a suitable water-immiscible solvent such as methyl acetate, ethyl acetate or methylene chloride. Meanwhile, the reducing agent or oxidizing agent is dissolved in water. The water solution can then be added to the solution of

15 encapsulant and water-immiscible solvent. Stirring or other high speed shear techniques preferably are used to promote uniform microcapsule formation. The capsule shells are formed around the aqueous solution droplets either by evaporation of the water-immiscible solvent

20 or by the addition of a second water-immiscible solvent (e.g., n-hexane) that will precipitate the encapsulant. The capsules can then be removed by cooling and filtration.

To encapsulate the reducing agent or oxidizing

25 agent in a water-soluble encapsulant, the dry reducing agent or oxidizing agent is preferably suspended in a stirred solution of the encapsulant in a water-immiscible organic solvent. Vigorous stirring will promote uniform encapsulation of the reducing agent or

30 oxidizing agent. The capsules can be formed by evaporation or by precipitation and then removed using the techniques described above.

The First Adhesive or the Second Adhesive can optionally contain a chelating agent. Preferred

35 chelating agents include tartaric acid, ethylene diamine tetraacetic acid, citric acid, the salts of these acids, and the like.

The First Adhesive or the Second Adhesive can also optionally contain a metal or alloy powder to assist in adhering to the amalgam. Preferred metal or alloy powders include metals of Group IVA, VA, VIA, VIIA, VIII, IB, and IIB, aluminum, indium, or thallium of Group IIIB, or tin or lead of Group IVB, or alloys thereof. Conventional dental amalgam alloy powders, typically mixtures of silver, tin, copper and zinc are also suitable.

10 If desired, the First Adhesive or the Second Adhesive can contain adjuvants such as pigments, nonreactive fillers, inhibitors, accelerators, viscosity modifiers, surfactants, and other ingredients that will be apparent to those skilled in the art.

15 The First Adhesive and the Second Adhesive can be mixed and clinically applied using a variety of techniques. However, a preferred series of steps is as follows:

(a) apply a "Pretreatment" to the enamel (and ~~the dentin~~); rinse with water;

(b) dry the Pretreatment film;

(c) mix and apply to the enamel or dentin one or more thin coats of the First Adhesive;

(d) preferably cure (and optionally, photocure) the First Adhesive;

(e) mix and apply to the First Adhesive one or more thin coats of the Second Adhesive;

(f) allow the Second Adhesive to harden without photocuring; and

30 (g) triturate and condense the amalgam onto the Second Adhesive.

Etchants for use in step (a) above should promote formation of a strong long-lasting bond to dentin or enamel. Suitable etchants include monomeric, oligomeric and polymeric organic and inorganic acids such as maleic acid, phosphoric acid, nitric acid, oxalic acid, citric acid, thylenediamine tetraacetic

acid (EDTA), methacrylic acid, polyacrylic acid, itaconic acid and mixtures thereof.

Amalgams for use in step (g) above should adhere well to the Second Adhesive and form a safe, strong, long-lasting restoration. Suitable amalgams include "DISPERSALLOY" and "UNISON" amalgams (Johnson & Johnson Dental Products, Inc.), "TYTIN" and "CONTOUR" amalgams (Kerr Manufacturing Co.) and "VALIANT" amalgam (L. D. Caulk Division of Dentsply International, Inc.).

The adhesives will have particular utility in clinical amalgam applications where rapid cure, preservation of sound tooth structure, tooth strengthening, fluoride release or microleakage reduction are desired. Such applications include posterior restorations, cervical restorations and deep restorations. The two-way dark cure mechanism in the First Adhesive and Second Adhesive facilitates uniform cure and early bond formation. The redox cure mechanism in the Second Adhesive appears to enhance dentin bond strength.

The adhesives as described above may be provided together with the other components as used in the described process in the form of kits. Specifically, a kit may comprise one or more adhesive(s) as described above, together with a restorative for application on top of the adhesive composition.

The invention is further described in the following illustrative examples, which should not be construed as limiting the scope of the invention. Unless otherwise indicated, all parts and percentages are on a weight basis.

**EXAMPLE 1****Adhesive Prepared Using Reducing Agent  
And Oxidizing Agent**

A test solution was prepared by combining the  
5 ingredients set out below in Table Ia:

**Table Ia**

Ingredients	Parts
Water	30
Acrylamide	30
Methylene bis-acrylamide	3

10 In a series of four runs a 2g portion of the test  
solution was placed in a glass test tube. For each  
15 run, 2% of the ingredients set out below in Table Ib  
were added to a separate test tube with shaking:

Run No.	Added Ingredients
1	Potassium Persulfate Ascorbic Acid
2	Potassium Persulfate Thiourea
3	Potassium Persulfate Oxalic Acid
4	Ammonium Persulfate Ascorbic Acid
5	Potassium Persulfate Sodium Sulfite
6	Benzoyl Peroxide Ascorbic Acid
7	Benzoyl Peroxide EDMAB <sup>1</sup>

<sup>1</sup> Ethyl 4-dimethylaminobenzoate

The contents of the two test tubes were combined with shaking. For Run nos. 1-5, gelation and an exotherm were observed within ten minutes. In Run nos. 6 and 7, no gelation was seen at 30 minutes.

5 The ingredients set out below in Table IIa were mixed, melted in an arc furnace at about 1350-1450°C, poured from the furnace in a thin stream and quenched using chilled rollers to provide an amorphous single-phase fluoroaluminosilicate glass:

10

Table IIa

Ingredient	Parts
SiO <sub>2</sub>	37
AlF <sub>3</sub>	23
SrO	20
Al <sub>2</sub> O <sub>3</sub>	10
AlPO <sub>4</sub>	7
Na <sub>3</sub> AlF <sub>6</sub>	6
P <sub>2</sub> O <sub>5</sub>	4

15

20

The glass was ball-milled to provide a pulverized frit with a surface area of 2.9 m<sup>2</sup>/g measured using the Brunauer, Emmet and Teller (BET) method, and labeled "Control Glass".

25

20 Parts of the Control Glass were independently mixed with 0.1 parts ascorbic acid (a water-soluble reducing agent) and 0.02 parts potassium persulfate (a water-soluble oxidizing agent) each dissolved in 39.5 parts methanol. Each solution was stirred for 10 minutes using a magnetic stirrer. Each wet glass was poured into a dish to a depth less than 1 cm, and then dried in a 45°C oven for 16 hours. Each dried glass was sieved through a 74 μm mesh screen.

30

35 The ascorbic acid-containing glass was labeled "Powder A" and the potassium persulfate-containing glass was

-20-

labeled "Powder B". Equal weights of Powder A and Powder B were combined, and labeled "Powder C".

The ingredients set out below in Table IIb were mixed using a paint shaker to provide an adhesive-forming liquid.

Table IIb

Ingredient	Adhesive-forming liquid, parts
Copolymer <sup>1</sup>	43
HEMA <sup>2</sup>	3.2
Water <sup>3</sup>	1.3
TUDMA <sup>4</sup>	0.6
(C <sub>6</sub> H <sub>5</sub> ) <sub>2</sub> I <sup>+</sup> PF <sub>6</sub> <sup>-</sup>	0.2
CPQ <sup>5</sup>	0.025

<sup>1</sup> Ethylenically-unsaturated acidic copolymer prepared like the precipitated dry polymer of EXAMPLE 11 of European Published Pat. Application No. 0 323 120, except that 63.6 parts IEM dissolved in 50 parts THF was used. The structure of the copolymer was confirmed by nuclear magnetic resonance spectroscopy.

<sup>2</sup> 2-Hydroxyethyl methacrylate.

<sup>3</sup> Distilled water.

<sup>4</sup> Trimethylhexamethylene urethane dimethacrylate.

<sup>5</sup> Camphorquinone.

Powder C and the liquid of Table IIb were hand-spatulated at a 1.4:1 powder:liquid ratio to provide an adhesive. The adhesive was evaluated for shear bond strength using the procedure outlined below. The results are reported in Table III below.

Bovine teeth of similar age and appearance were partially embedded in circular acrylic disks. The exposed portion of each tooth was ground flat and parallel to the acrylic disc using Grade 120 silicon carbide paper-backed abrasive mounted on a lapidary wheel, until the dentin or enamel was exposed. Further



-21-

grinding and polishing of the teeth was carried out by mounting Grade 320 silicon carbide paper-backed abrasive and then Grade 600 silicon carbide-backed abrasive on the lapidary wheel. During the grinding and polishing steps, the teeth were continuously rinsed with water. The polished teeth were stored in distilled water and used for testing within 2 hours after polishing. The polished teeth were removed from the water and dried using a stream of compressed air.

10 A Pretreatment of phosphoric acid etching gel was applied to the enamel or dentin for 15 to 30 seconds, rinsed with water and dried. At this point, the adhesive composition of the invention was applied to the enamel or dentin surface with a spatula or ball applicator in either "One Coat" or "Two Coats".

15 In the One Coat method, a mold made from a 2 mm thick "TEFLON" polytetrafluoroethylene sheet with a gelatin sleeve having an inner area of 0.20 cm<sup>2</sup> was clamped to the uncured adhesive layer so that the central axis of the hole in the mold was normal to the polished tooth surface. The hole in each mold was filled with triturated TYTIN amalgam and allowed to stand for 10-15 minutes at room temperature to allow the adhesive layer to autocure ("Autocured"). The molds were then stored in distilled water at 37°C for 24 hours.

20 In the Two Coat technique, the first coat was cured using a 20-30 second irradiation with a dental curing light ("VISILUX 2", 3M) ("Light-cured"). A second coat of adhesive was applied atop the first coat, allowed to autocure and the mold filled with triturated amalgam. The molds were allowed to stand at room temperature for 10-15 minutes and then stored in water as described in the One Coat method.

35 The molds were then carefully removed, leaving a molded amalgam button attached to each tooth. Adhesive strength was evaluated by mounting the acrylic

disk in a holder clamped in the jaws of an "INSTRON" tensile testing apparatus with the polished tooth surface oriented parallel to the direction of pull. A loop of 0.44 mm diameter orthodontic wire was placed around the base of the amalgam button adjacent to the polished tooth surface. The ends of the orthodontic wire were clamped in the pulling jaw of the tensile testing apparatus, placing the bond in shear stress. The bond was stressed until it (or the amalgam button) failed, using a crosshead speed of 2 mm/min and an average of 5 or more samples.

Table III

Adhesion Method	Shear Adhesion to Enamel (MPa)
One Coat: Autocured	6.9
Two Coats: First - Light-cured Second - Autocured	8.0

**PREPARATORY EXAMPLE 1****Preparation of Silanol Treated Glass**

4 Parts gamma-methacryloxypropyl trimethoxysilane ("A-174", Union Carbide Corp.), 0.44 parts glacial acetic acid, 25 parts methanol, and 25 parts water were mixed. The mixture was stirred for 15 minutes at room temperature, yielding a silanol-containing treating solution. 100 Parts of the Control Glass of EXAMPLE 1 were combined with the silanol treating solution, slurried for 1.5 hours at room temperature, poured into shallow trays, dried overnight at 45°C, and sieved through a 74  $\mu$ m mesh screen.

**PREPARATORY EXAMPLE 2****Preparation of Microencapsulated  
Oxidizing Agent and Reducing Agent**

Two separate solutions whose compositions are  
5 set out below in Table IV were each placed in separate  
addition funnels:

**Table IV**

Run No.	Solution
10 1	3 parts ascorbic acid in 60 parts water
2	3 parts $K_2S_2O_8$ in 60 parts water

In a series of two separate runs, 50 parts of one of  
the solutions shown above were added to 366 parts of a  
15 stirred 1% solution of cellulose acetate butyrate (CAB)  
in ethyl acetate contained in a stainless steel vessel  
immersed in a 4°C water bath. The stirrer speed was  
maintained at 700 rpm and the bath temperature was  
maintained at 4°C. 267 Parts of ice cold n-hexane were  
20 added dropwise to the stirred solution over a 30 minute  
period. Granular spherical microcapsules were formed,  
as evidenced by microscopic examination. Stirring was  
continued for an additional 15 minutes. The granular  
precipitate was filtered, washed with ice-cold n-  
25 hexane, dried under vacuum and then deagglomerated in  
an electric coffee mill.

**EXAMPLE 2****Preparation of Adhesives Using Microencapsulated  
30 Oxidizing Agent And Reducing Agent**

Four glass powder compositions were prepared  
by tumbling the ingredients set out below in Table V in  
a mill for 1 hour. The silanol treated glass, the  
microencapsulated ascorbic acid/CAB and the  
35 microencapsulated potassium persulfate/CAB were

prepared in PREPARATORY EXAMPLES 1 and 2. The micronized CAB was obtained by comminuting CAB in a chopping mill.

5

Table V

Ingredient	Parts			
	Powder D	Powder E	Powder F	Powder G
10 Silanol Treated Glass	100	100	100	100
Microencapsulated Ascorbic Acid/CAB	--	0.55	--	0.55
Microencapsulated K <sub>2</sub> S <sub>2</sub> O <sub>8</sub> /CAB	--	0.09	--	--
15 Micronized CAB	--	--	0.6	--

Three adhesive-forming liquids were prepared by mixing on a paint shaker the ingredients set out below in Table VI:

Table VI

Ingredient	Adhesive-forming liquids, parts		
	Liquid A	Liquid B	Liquid C
Copolymer <sup>1</sup>	50	50	50
Water	30	30	30
HEMA	20	20	20
25 (C <sub>6</sub> H <sub>5</sub> ) <sub>2</sub> I <sup>+</sup> PF <sub>6</sub> <sup>-</sup>	1.0	--	1.0
CPQ	0.25	--	0.25
BPO <sup>2</sup>	--	--	0.25
BHT <sup>3</sup>	0.05	0.05	0.05

30 <sup>1</sup> Ethylenically-unsaturated acidic copolymer prepared like the precipitated dry polymer of EXAMPLE 11 of European Published Pat. Application No. 0 323 120.

35 <sup>2</sup> Benzoyl peroxide - did not dissolve, but remained in suspension.

<sup>3</sup> Butylated hydroxytoluene.

In a series of 6 runs, the powders of Table V and the liquids of Table VI were hand-spatulated at a 1.4:1 powder:liquid ratio. The adhesives were tested for adhesion to dentin following the procedure of

5 EXAMPLE 1, except that DISPERSALLOY instead of TYTIN amalgam was used. For each run, two coats of adhesive were applied. The first coat was light-cured and the second coat was allowed to autocure. The results are set out below in Table VII, along with a brief

10 identification of the applicable cure mechanism for each run.

Table VII

Run No.	First Coat			Second Coat			Adhesion to Dentin (MPa)
	Powder	Liquid	Cure Mechanism	Powder	Liquid	Cure Mechanism	
1	E	A	IPR <sup>1</sup>	E	A	IR <sup>2</sup>	12.0
2	D	A	IP <sup>3</sup>	E	B	IR	7.3
3	D	A	IP	D	B	I <sup>4</sup>	1.2
4	D	A	IP	F	B	I	0.8
5	D	A	IP	G	B	I	0.4
6	G	C	IP	G	C	I	0.4

1 "IPR" = Acid-base ionomer reaction ("R") plus photoinitiated reaction ("P") plus redox reaction ("R").

2 "IR" = I reaction plus R reaction.

3 "IP" = I reaction plus P reaction.

4 "I" = I reaction.

The results in Table VII illustrate the improvement provided by the invention. The adhesion values obtained for the samples of Run nos. 1 and 2 were the best and were 7-10 times higher than the values obtained for samples of the Run nos. 3-6. Run no. 2 shows that the oxidizing agent and the reducing agent are not essential in the first coat, but both are needed in the second coat since their absence in the second coat (Run nos. 3 and 4) gave very poor adhesion values. In Run nos. 3-6, all failures were in the second coat with the first coat remaining intact on the dentin. The CAB in Run no. 4 did not contribute to adhesion. The incorporation of only one of the redox pair in the second coat of Run no. 5 did not improve adhesion. In Run no. 6 benzoyl peroxide oxidizing agent and ascorbic acid reducing agent were used. This combination gave unexpectedly poor adhesion values, probably do to the fact that the benzoyl peroxide did not appreciably dissolve in the liquid and therefore was not effective in the composition of the invention.

As a further comparison, in a series of 4 runs, adhesion values at specific time intervals were measured.

Powders of Table V and liquids of Table VI were hand-spatulated at a 1.4:1 powder:liquid ratio, then tested for adhesion following the procedure of EXAMPLE 1, except that the dentin was not pretreated prior to application of the adhesive. For each run, two coats of adhesive were applied. The first coat was light-cured for Run nos. 1 and 3, but allowed to autocure for Run nos. 2 and 4. The second coat was allowed to autocure in each of the runs. The results are set out below in Table VIII, along with a brief identification of the applicable cure mechanism for each run.



Table VIII

Run No.	First Coat				Second Coat				Adhesion to Dentin (MPa)			
	Powder	Liquid	Photo-curing	Cure Mechanism	Powder	Liquid	Cure Mechanism		Immed.	15 min.	1 hr.	24 hr.
1	E	A	Yes	IPR		A	IR		2.0	5.3	9.2	7.1
2	E	A	No	IR		A	IR		0	2.5	2.0	2.7
3	vitre-bond	vitre-bond	Yes	IP	vitre-bond	vitre-bond	I		0	1.0	0.5	1.8
4	G	C	No	I		C	I		0	0	0	0

The results in Table VIII further illustrate the improvement provided by the invention. When all three curing mechanisms (Run no. 1) were present and the first coat was light-cured and the second coat was allowed to autocure, much higher adhesion values were obtained than when the photoinitiated "P" reaction was omitted after the first coat was applied (Run no. 2). Run no. 1 is a substantial improvement over the commercially available composition of Run no. 3 ("VITREBOND" Light Cure Glass Ionomer Liner/Base) where the second layer can undergo only the ionomer "I" reaction. The composition of Run no. 1 exhibited a high adhesion value immediately, whereas the compositions of Run nos. 2-4 exhibited no adhesion. This immediate high adhesion is important insofar as this allows the dentist to perform subsequent procedures on the tooth without waiting. In Run no. 4, where benzoyl peroxide was used instead of the oxidizing agent of the invention, no adhesion was obtained at any of the time intervals.

### EXAMPLE 3

#### Effect of Pretreatment on Adhesion to Dentin

In a series of 5 runs, Powder E of EXAMPLE 2 (Table V) with a surface area of  $2.8 \text{ m}^2/\text{g}$  instead of  $2.9 \text{ m}^2/\text{g}$  and Liquid A of EXAMPLE 2 (Table VI) were hand-spatulated at a 1.4:1 powder:liquid ratio. The samples were tested for adhesion to dentin following the procedure of EXAMPLE 1, except that a different Pretreatment was used for Run nos. 1-2 and 4-5. For Run nos. 1 and 2, no Pretreatment was applied to the prepared dentin prior to application of the adhesive. In Run no. 4, a Pretreatment with a solution of 8% maleic acid in water was applied instead of the phosphoric acid etching gel of EXAMPLE 1. For Run no. 5, a Pretreatment with a solution of water, HEMA, Copolymer and maleic acid was applied to the dentin

-30-

without rinsing after the application, dried and then the adhesive applied. The amalgam used was DISPERSALLOY. The shear adhesion values are set out below in Table IX, along with a brief identification of the applicable cure mechanism for each run.

Table IX

Run No.	Pre-treatment	First Coat Cure Mechanism	Second Coat Cure Mechanism	Shear Adhesion to Dentin (MPa)
1	none	IP	---	1.9 <sup>1</sup>
2	none	IP	IR	6.0
3	PA <sup>2</sup>	IP	IR	6.5
4	MA <sup>3</sup>	IP	IR	8.6
5	S <sup>4</sup>	IP	IR	4.1

<sup>1</sup> 10 samples tested.

<sup>2</sup> Phosphoric acid etching gel.

<sup>3</sup> 8% Maleic acid in water.

<sup>4</sup> A solution of:

75 parts H<sub>2</sub>O

15 parts HEMA

5 parts copolymer of EXAMPLE 2 (Table VI)

5 parts maleic acid

The results in Table IX show that when no Pretreatment was applied to the dentin prior to application of the adhesive, the Two Coat technique (Run no. 2) provided higher adhesion values than the One Coat method (Run no. 1). The maleic acid Pretreatment of Run no. 4 provided somewhat higher adhesion to dentin than the Pretreatments of either Run no. 3 or 5.

**EXAMPLE 4****Effect of Various Amalgams on Adhesion to Enamel**

5        In a series of 5 runs, the procedure of  
EXAMPLE 3 was followed, except that amalgams other than  
DISPERSALLOY were used and adhesion to enamel instead  
of dentin was measured. The shear adhesion values are  
set out below in Table X, along with the Pretreatment,  
the amalgam, and a brief identification of the  
10       applicable cure mechanism for each run.

Table X

Run No.	Pretreatment	First Coat Cure Mechanism	Second Coat Cure Mechanism	Amalgam	Shear Adhesion to Enamel (MPa)
1	PA	IR	---	UNISON	14.3
2	PA	IR	---	DISPERSALLOY	14.8
3	MA	IP	IR	UNISON	13.8
4	MA	IP	IR	DISPERSALLOY	12.5
5	MA	IP	IR	TYTIN	10.1

The results in Table X show that the amalgam used had little effect on adhesion irregardless of whether a Pretreatment was applied and whether the One Coat or Two Coat technique was utilized.

5

**EXAMPLE 5****Effect of Thermocycling on Adhesion to  
Dentin and Enamel**

10 In a series of 6 runs, the procedure of  
EXAMPLE 3 was followed, except that DISPERSALLOY or  
UNISON amalgam was used, the samples were thermocycled  
and adhesion to both dentin and enamel was measured.  
In Run nos. 2, 4 and 6, instead of storing the molds in  
15 distilled water at 37°C for 24 hours, the molds were  
thermocycled between 5°C and 50°C water baths for at  
least 500 cycles with dwell times of 30 seconds in the  
baths and an interval of 15 seconds between the baths.  
The shear adhesion values are set out below in Table  
20 XI, along with the Pretreatment, the amalgam, whether  
or not thermocycling was done and a brief  
identification of the applicable cure mechanism for  
each run.

Table XI

Run No.	Pre-treatment	First Coat Cure Mechanism	Second Coat Cure Mechanism	Amalgam	Thermo-cycled	Shear Adhesion (MPa)	
						Dentin	Enamel
1	PA	IP	IR	DISPERS-ALLOY	No	9.7	---
2	PA	IP	IR	DISPERS-ALLOY	Yes	16.9	---
3	MA	IP	IR	DISPERS-ALLOY	No	14.3	11.7
4	MA	IP	IR	DISPERS-ALLOY	Yes	15.5	14.8
5	MA	IP	IR	UNISON	No	---	16.0
6	MA	IP	IR	UNISON	Yes	---	18.1



The results in Table XI show that thermocycling did not adversely effect adhesion to either dentin or enamel and in Run no. 2 significantly increased adhesion.

5

**EXAMPLE 6****Modification of a Commercial Ionomer Powder**

5.8 Parts "GC Fuji LC" light-curable glass ionomer powder (G-C Dental Industrial Corp.) were combined with 0.0322 parts of the ascorbic acid microcapsules of Run no. 1 of PREPARATORY EXAMPLE 2 and 0.0058 parts of the potassium persulfate microcapsules of Run no. 2 of PREPARATORY EXAMPLE 2. The resulting powder mixture was rolled-milled for one half hour. The powder was labeled "Modified GC Powder". The Modified GC Powder was combined at a 1.4: powder:liquid ratio with the GC Fuji LC liquid supplied by the manufacturer.

As a comparison, Powder E used in EXAMPLE 3 and Liquid A of EXAMPLE 2 (Table VI) were combined at a 1.4:1 powder:liquid ratio. The modified GC composition and the composition of the invention were tested for adhesion to enamel following the procedure of EXAMPLE 1. Two coats were applied with the First Coat light-cured and the Second Coat allowed to autocure. The shear adhesion values for each adhesive are set out below in Table XII.

**Table XII**

30

Adhesive Powder	Shear Adhesion to Enamel (MPa)
Modified GC Powder	11.7
Powder E (EXAMPLE 3)	12.0

35

The results in Table XII illustrate that when a commercial glass ionomer powder was modified to contain the oxidizing agent and reducing agent of the

-36-

adhesives of the invention, a composition exhibiting shear adhesion to enamel values comparable to that of a composition of the invention was obtained.

5

**EXAMPLE 7****Modification of a Commercial Amalgam Adhesive**

In a first run, the procedure of EXAMPLE 1 was followed by a Pretreatment of the enamel with 37% phosphoric acid etchant gel. After rinsing and drying, a second Pretreatment consisting of a solution of 10 parts of the copolymer of EXAMPLE 2 (Table VI), 36 parts HEMA and 54 parts water was applied to the enamel and dried. AMALGAMBOND B liquid was applied to the pretreated enamel. Triturated DISPERSALLOY amalgam was condensed atop the AMALGAMBOND B liquid coat and the adhesion value obtained using the procedure of EXAMPLE 1 was 0.05 MPa.

As a second run, the procedure of the first run was followed, except that two coats of AMALGAMBOND

first coat was light-cured and the second coat was allowed to autocure. The adhesion value obtained was 0.07 MPa.

In a third run, the procedure of the first run was followed, except that the AMALGAMBOND B liquid was hand-spatulated at a 1:4 powder:liquid ratio with Powder E of EXAMPLE 2 (Table V) and the resultant adhesive applied in one coat and allowed to autocure. The adhesion value obtained was 6.5 MPa.

In a fourth run, the procedure of the third run was followed, except that the resultant adhesive was applied in two coats, the first was light-cured and the second was allowed to autocure. The adhesion value obtained was 12.9 MPa.

As a comparison, AMALGAMBOND was applied according to the manufacturer's instructions to the

-37-

pretreated enamel as detailed in the first run. The adhesion value obtained was only 2.3 MPa.

5 This demonstrates that a commercial amalgam adhesiv can exhibit much higher adhesion value when modified to be similar to the adhesives of the invention and applied in two coats, the first of which is light-cured and the second being allowed to autocure.

10 Although this invention has been described using certain illustrative examples, it should be understood that the invention is not limited to the specific exemplary embodiments shown in this specification.

**WE CLAIM:**

1. A water-containing ionically-hardenable,  
ethylenically-unsaturated dental adhesive composition  
5 consisting of

- a) finely-divided acid-reactive filler,
- b) water-miscible acidic polymer,
- c) water-soluble reducing agent, and
- d) water-soluble oxidizing agent.

10

2. An adhesive according to claim 1, wherein  
the filler comprises metal oxide, metal salt or glass.

3. An adhesive according to claim 2, wherein  
15 the glass comprises fluoroaluminosilicate glass.

4. An adhesive according to claim 1, wherein  
the polymer comprises a homopolymer or copolymer of an  
alkenoic acid.

5. An adhesive according to claim 4, wherein  
the polymer comprises a copolymer of acrylic acid  
containing one or more ethylenically-unsaturated  
groups.

25

6. An adhesive according to claim 1,  
containing as a further component an ethylenically-  
unsaturated monomer.

30

7. An adhesive according to claim 1, wherein  
the reducing agent and the oxidizing agent are capable  
of initiating gelation of a 10:10:1 weight basis  
water:acrylamide:methylene bis-acrylamide mixture.

35

8. An adhesiv according to claim 1, wherein the reducing agent is selected from the group consisting of ascorbic acid, cobalt (II) chloride, ferrous chloride, ferrous sulfate, hydrazine, oxalic acid, thiourea, and salts of a dithionite or sulfite anion.

9. An adhesive according to claim 1, wherein the reducing agent comprises ascorbic acid or thiourea.

10

10. An adhesive according to claim 1, wherein the oxidizing agent is selected from the group consisting of cobalt (III) chloride, tert-butyl hydroperoxide, ferric chloride, perboric acid and its salts, and salts of a permanganate or persulfate anion.

15

11. An adhesive according to claim 1, wherein the oxidizing agent comprises potassium or ammonium persulfate.

20

12. An adhesive according to claim 1, wherein the adhesive has two parts respectively containing glass and polymer, and one agent is packaged with the glass and the other agent is packaged with the polymer.

25

13. An adhesive according to claim 1, further comprising a chelating agent.

14. An adhesive according to claim 13, wherein said chelating agent is selected from the group consisting of tartaric acid, ethylene diamine tetraacetic acid, citric acid, and the salts thereof.

30

15. An adhesive according to claim 1, further comprising metal or alloy powder.

35

16. A method of adhering a metal or metal-containing restorative to a hard tissue comprising

a) applying an adhesively effective amount of a water-containing ionically-hardenable, ethylenically-unsaturated dental adhesive composition consisting of

- i) finely-divided acid-reactive filler,
- ii) water-miscible acidic polymer,
- iii) water-soluble reducing agent, and
- iv) water-soluble oxidizing agent

to the hard tissue; and

b) placing said restorative on top of said adhesive composition.

17. A method of adhering a metal or metal-containing restorative to hard tissue comprising

a) applying an adhesively effective amount of a first adhesive that is a water-containing ionically-hardenable, ethylenically unsaturated dental

- i) finely-divided acid-reactive filler,
- ii) water-miscible acidic polymer,

to the hard tissue;

- iii) water-soluble reducing agent; and

- iv) water-soluble oxidizing agent.

b) curing said first adhesive;

c) applying an adhesively effective amount of a second adhesive that is a water-containing ionically-hardenable, ethylenically-unsaturated dental adhesive composition comprising

- i) finely-divided acid-reactive filler,
- ii) water-miscible acidic polymer,
- iii) water-soluble reducing agent, and
- iv) water-soluble oxidizing agent

to the first adhesive;

d) placing said restorative on top of said second adhesive composition.



-41-

18. The method of adhering a metal or metal-containing restorative to hard tissue comprising

- a) applying an adhesively effective amount of a first adhesive that is a water-containing ionically-hardenable, ethylenically-unsaturated dental adhesive composition comprising
  - i) finely-divided acid-reactive filler,
  - ii) water-miscible acidic polymer, and
  - iii) a photoinitiatorto the hard tissue;
- b) curing said first adhesive by exposure to visible light;
- c) applying an adhesively effective amount of a second adhesive that is a water-containing ionically-hardenable, ethylenically-unsaturated dental adhesive composition comprising
  - i) finely-divided acid-reactive filler,
  - ii) water-miscible acidic polymer,
  - iii) water-soluble reducing agent, and
  - iv) water-soluble oxidizing agent,
- d) placing said restorative on top of said second adhesive composition.

19. The method of claim 18, wherein said second adhesive further comprises a photoinitiator.

20. The method of claim 17, comprising

- a) applying an adhesively effective amount of a first adhesive that is a water-containing ionically-hardenable, ethylenically-unsaturated dental adhesive composition comprising
  - i) finely-divided acid-reactive filler,
  - ii) water-miscible acidic polymer,
  - iii) water-soluble reducing agent,
  - iv) water-soluble oxidizing agent, and
  - v) a photoinitiator

to the hard tissue;

b) curing said first adhesive by exposure to visible light;

5 c) applying an adhesively effective amount of a second adhesive that is a water-containing ionically-hardenable, ethylenically-unsaturated dental adhesive composition comprising

- 10 i) finely-divided acid-reactive filler,
- ii) water-miscible acidic polymer,
- iii) water-soluble reducing agent,
- iv) water-soluble oxidizing agent, and
- v) a photoinitiator

to the first adhesive; and

15 d) placing said restorative on top of said second adhesive composition.

21. A kit for adhering metal or metal-containing restorative to hard surfaces comprising

a) a metal or metal-containing restorative;

b) an adhesive adapted to adhere said restorative to hard surfaces that is a water-containing ionically-hardenable, ethylenically-unsaturated dental adhesive composition comprising

- 25 i) finely-divided acid-reactive filler,
- ii) water-miscible acidic polymer,
- iii) water-soluble reducing agent, and
- iv) water-soluble oxidizing agent.

30 22. The kit of claim 21, wherein said adhesive further comprises a photoinitiator.

## INTERNATIONAL SEARCH REPORT

International Application No

PCT/US. 92/10939

<b>I. CLASSIFICATION F SUBJECT MATTER</b> (if several classification symbols apply, indicate all) <sup>6</sup>		
According to International Patent Classification (IPC) or to both National Classification and IPC		
Int.Cl. 5 A61K6/00; A61K6/083		
<b>II. FIELDS SEARCHED</b>		
Minimum Documentation Searched <sup>7</sup>		
Classification System	Classification Symbols	
Int.Cl. 5	A61K	
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched <sup>8</sup>		
<b>III. DOCUMENTS CONSIDERED TO BE RELEVANT<sup>9</sup></b>		
Category <sup>10</sup>	Citation of Document, <sup>11</sup> with indication, where appropriate, of the relevant passages <sup>12</sup>	Relevant to Claim No. <sup>13</sup>
P,X	WO,A,9 211 837 (MINNESOTA MINING AND MANUFACTURING COMPANY) 23 July 1992 see page 5, line 25 - page 11, line 3; claims	1-20
P,X	US,A,5 154 762 (S. MITRA) 13 October 1992 see the whole document	1-22
X	WO,A,8 805 651 (DENTAL COMPOSITE LTD) 11 August 1988 see page 3, line 5 - line 31; claims	1-6, 16-21
Y	EP,A,0 323 120 (MINNESOTA MINING AND MANUFACTURING COMPANY) 5 July 1989 cited in the application see page 2, line 45 - line 55; claims	1-14, 16-17
-/--		
<sup>10</sup> Special categories of cited documents : "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier document but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art. "&" document member of the same patent family		
<b>IV. CERTIFICATION</b>		
Date of the Actual Completion of the International Search		Date of Mailing of this International Search Report
15 MARCH 1993		07. 04. 93
International Searching Authority		Signature of Authorized Officer
EUROPEAN PATENT OFFICE		G.COUSINS- VAN STEEN

Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.
Y  A	<p>EP,A,0 413 174 (MITSUBISHI RAYON CO.)            20 February 1991            see page 6, line 54 - page 7, line 36;            claims</p> <p style="text-align: center;">----</p> <p>US,A,4 064 629 (G. STONER)            27 December 1977            cited in the application            see claims</p> <p style="text-align: center;">-----</p>	<p>1-14, 16,            17</p> <p>15</p>

ANNEX TO THE INTERNATIONAL SEARCH REPORT  
ON INTERNATIONAL PATENT APPLICATION NO.

US 9210939  
SA 68345

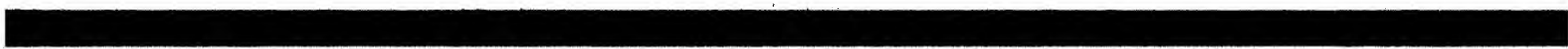
This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.  
The members are as contained in the European Patent Office EDP file on  
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15/03/93

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		SE-A- 7700772	27-07-77

FORM P0419

The first part of the document is a list of names and addresses. The names are written in a cursive hand, and the addresses are written in a more formal, printed hand. The list is organized into two columns, with names on the left and addresses on the right. The names are: John Smith, James Brown, William Jones, Robert Taylor, and Thomas White. The addresses are: 123 Main Street, New York, NY; 456 Elm Street, New York, NY; 789 Oak Street, New York, NY; 101 Pine Street, New York, NY; and 202 Cedar Street, New York, NY.



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